DOCUMENT RESUME

ED 270 636 CE 044 597

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TITLE Technical Skills Acquisition: Aptitude-Treatment Interactions, Heuristics and Teacher Behavior.
PUB DATE Apr 86
NOTE 11p.; Paper presented at the Annual Meeting of the American Educational Research Association (70th, San Francisco, CA, April 16-20, 1986).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Aptitude Treatment Interaction; Classroom Techniques; Educational Needs; Electronics; Foreign Countries; *Heuristics; Metal Working; Postsecondary Education; *Psychomotor Skills; Secondary Education; *Skill Development; Spatial Ability; *Task Analysis; Teacher Attitudes; Teacher Behavior; Vocational Education; *Vocational Education Teachers
IDENTIFIERS Netherlands

ABSTRACT

Two studies were conducted to determine how students perform psychomotor tasks and how teacher behavior influences performance. Study 1, conducted with about 100 technical students in a metal working class in a technical school in The Netherlands, showed that a process-based heuristic approach, stimulating students to perform complex psychomotor tasks in their own way, can help both high and low ability students. Heuristic instructions permit students not having problems to proceed quickly through the successive processes that lead to the product. However, for students who encounter a problem, suggestions as to the means to deal with it are available. At any stage students themselves control each step of task performance, thereby strengthening their self-regulation capacities. Study 2, conducted with 18 teachers, 10 metal work teachers, and 8 electrotechnics teachers, recorded their verbal behavior during regular practice lessons lasting about 1.5 hours each. The study showed that technical school teachers are inclined to exercise extensive control over student performance. Taking into account the results of study 1 and of earlier studies, such teacher control should be regarded as ineffective: high ability students' performance will be lessened, while for low ability students only short-term effects are expected. Control over task performance should, therefore, be shifted from teacher to student. Teachers' instructions will be more effective when they put students in a position where they can invent solutions for problems and develop performance routines themselves. Special emphasis should also be put on the process of goal-image formation. (KC)

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Paper presented on 1986 AERA-meeting in San Francisco USA

TECHNICAL SKILLS ACQUISITION: APTITUDE-TREATMENT INTERACTIONS, HEURISTICS AND TEACHER BEHAVIOR

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Introduction

The research project "Psychomotor skills in technical schools" is being carried out at Tilburg University and Eindhoven University of Technology. The project focusses on rather complex psychomotor tasks requiring integration of several task-dependent part-skills and application of relevant knowledge. In performing metal work, for instance, students are required to study a design, to scribe a piece of metal, to choose suitable actions, to select appropiate tools, to determine the sequence of steps to be taken and to apply part-skills as sawing, filing and drilling. Evidently, in this type of task cognition plays a major role. Students have to solve technical problems, requiring a combination of thinking and doing.

Several studies have been performed as yet; the results of three of these have been presented at the 1985 AERA meeting in Chicago (Van der Sanden & Schouten, 1985). Based on rational task analyses (Resnick, 1976), it was suggested that efficient performance entails the following processes:

Goal-image formation: creating a mental image of the goals to be reached (cf. Singer, 1978).
Analysis: translating problem(s) into technical terms and considering steps to be taken.
Planning: ordering the required activities in a plan of action.
Execution: performing the planned activities.
Evaluation: monitoring ongoing performance and evaluating executed actions.

Some evidence for student differences in performing the oprations described above was found in an observational study of student behavior. Students having problems with goal-image formation, analysis and/or planning often fell into an unsuccesful trial-and-error strategy. Therefore the effects of various amounts of instructional support with regard to the required cognitive operations (cf. Tobias, 1982) were investigated.

In several studies the effectiveness of instructional support was found to be inversely related to students' spatial-technical ability. Low ability students performed best when highly supported, whereas extensive instructional support turned out to be detrimental for high ability students.

The above mentioned process model served as a basis for the two recently performed studies that are presented in this paper. In the first study the model formed the rationale for newly developed heuristic instructions. In the second study the model was used to generate a procedure to categorize teacher behavior.

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Study 1

Research questions

Providing a detailed teacher-made task-analysis and planning can be regarded as a way to externally regulate student behavior. Low ability students may lack adequate regulating skills. For these students external regulation serves a compensatory function. For high ability students, however, extensive external regulation, or teacher-control, seems to interfere with their capacities to regulate task-behavior themselves.

From diverse theoretical positions the development of learner self-control (i.e. "The capacity for independent regulation of his own mental processes and behavior," Landa, 1976) is considered a major educational goal. With respect to this long term goal, one can doubt the effectiveness of extensive teacher control over student performance. Such control actually disrupts high ability students' self-control, whereas for low ability students it enhances the danger of thoughtlessly following instructions, probably leading to short term effects only. Heuristic instructions, stimulating students to find their own way of coping with the task, seemed a reasonable alternative. So it was decided to investigate the effects of instructions of a heuristic nature.

Specific research questions for study 1 were:

Can the differential effects of high vs. low instructional support for students of different ability and prior achievement be overcome by means of a heuristic approach?

Will such an approach enhance low ability students' performance without damaging the performance of high ability students?

Design and method

About 100 lower grade students of technical schools participated in this study. Standardized tests were used to measure students' technical ability, spatial ability, field-independence and manual dexterity. To assess levels of prior achievement students made a simple piece of metal work according to a design. The design showed a front-, a top- and a sideview of the piece. No further instructions were given. Some weeks later the students constructed a more complex piece, viz. a screw-driver holder, under one of three conditions to which they were randomly assigned.

In the high-structure condition students performed the task according to a written, detailed analysis and planning. Students were obliged to follow the provided instructions.

In the low-structure condition students were given nothing but a design of the product. They had to decide upon all necessary operations themselves.

Finally in the heuristic condition students were given a written set of directives mainly concerning goal-image formation, analysis and planning. Students were asked to write down problems they had in understanding the design. If so, they were suggested to make a development scheme. Other directives in the list were, for example, to write down all executive actions first and then order these actions in a useful sequence.

Four weeks later students were informed about their results (raw maximum score: 68). They then made the screw-driver holder once more, all of them without written instructions.

As a dependent variable for each student the difference score of the first screw-driver holder and the second was calculated. Test scores were standardized and a composite 'spatial-technical intelligence score' (STI) was computed by averaging scores on technical ability, spatial ability, field-independence and manual dexterity. Students' results on the simple piece of metal work were used as a separate measure of prior achievement (PA).

Data were analyzed using multiple regression analyses (SPSS, Nie et al., 1975). Condition vectors were formed through contrast-coding (Kerlinger and Pedhazur, 1973). Predictors were entered in a pre-established hierarchy: learner characteristics first, condition vectors next and then learner-characteristic-by-condition interaction terms. Main effects of instructional conditions were tested for significance by entering the condition vectors only.

Results

Table 1 presents descriptive statistics concerning aptitude measures and the dependent variables for the entire sample (N=99).

Table 1: Means (M), Standarddeviations (SD) and Pearson-correlations concerning aptitudes and dependent variables (n=99)

Variable	M	SD	Pearson-correlations								
			1	2	3	4	5	6	7	8	9
1. spatial ability	57.53	16.96		.38**	.51**	.21*	.73**	.17	.37**	.26**	-.18
2. technical ability	40.59	8.46			.38**	.45**	.76**	.40**	.23*	.29**	.00
3. field(in)dependence	10.98	4.63				.29*	.75**	.19	.46**	.34**	-.21*
4. manual ability	13.02	4.70					.67**	.31**	.29**	.28**	-.07
5. STI	.07	.70						.37**	.47**	.40**	-.16
6. PA	36.76	9.69							.34**	.33**	-.09
7. Product 1	27.93	9.98								.48**	-.67**
8. Product 2	32.13	7.88									.33**
9. Difference-score	4.20	9.27									

* p ≤.05
** p ≤.01

Inspection of the mean productscores learns that students perform rather poorly, mean productscores for the screw-driver holder both times being lower than half the maximum score. Positive relations occur between spatial-technical intelligence, prior achievement and the productscores.

Table 2 shows mean productscores and standard deviations for each instructional condition.

Table 2: Mean product scores (M) and Standarddeviations (SD) by instructional condition (n=60 for each condition)

Instructional Condition	Product 1			Product 2			Difference scores		
	H	R	L	H	R	L	H	R	L
M	29.94	24.45	29.39	33.64	30.30	32.45	3.70	5.85	3.06
SD	11.01	9.04	9.11	8.22	7.73	7.56	10.34	8.35	9.04

H = High structure
R = Heuristics
L = Low structure

Regression analyses were run to test for differences between all possible orthogonal contrasts, none of them being significant.

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Tables 3 and 4 report the results of regression analyses that were run to test for interaction effects. Separately for STI and PA, the tables list information on the amount of variance accounted for (% var) by the interaction term, the F-value (F), the regression constant (a) and the regression slope (b).

Table 3: Interactions of spatial-technical intelligence (STI) and the instructional conditions (df=93)

Interactionterm	%VAR	F	Cond.	a	b
STIxHRL	3.79	3.85*			
STIxRL	.32	.33	H	3.94	-4.04
STIxLHR	1.64	1.66	R	5.85	-.70
STIxHR	2.48	2.51	L	3.10	.67
STIxRHL	.58	.59			
STIxHL	3.53	3.59*			

* p ≤.10

Table 4: Interactions of prior ability (PA) and the instructional conditions (df=93)

Interactionterm	%VAR	F	Cond.	a	b
PAxHRL	6.27	6.42**			
PAxRL	.73	.74	H	4.81	-3.94
PAxLHR	3.76	3.85*	R	5.88	.13
PAxHR	3.24	3.32	L	3.21	2.13
PAxRHL	.40	.41			
PAxHL	6.60	6.76**			

* p ≤.10
** p ≤.05

Definitions of abbreviations
PA : prior achievement
STI: spatial technical intelligence
HRL contrasts high structure with heuristics and low structure
RL contrasts heuristics with low structure
LHR contrasts low structure with high structure and heuristics
HR contrasts high structure with heuristics
RHL contrasts heuristics with high and low structure
HL contrasts high structure with low structure

As can be seen in tables 3 and 4 the significant interactions between spatial-technical intelligence and instructional conditions, respectively prior achievement and instructional conditions show the same pattern. Figure 1 shows a graphic representation of the interactions.

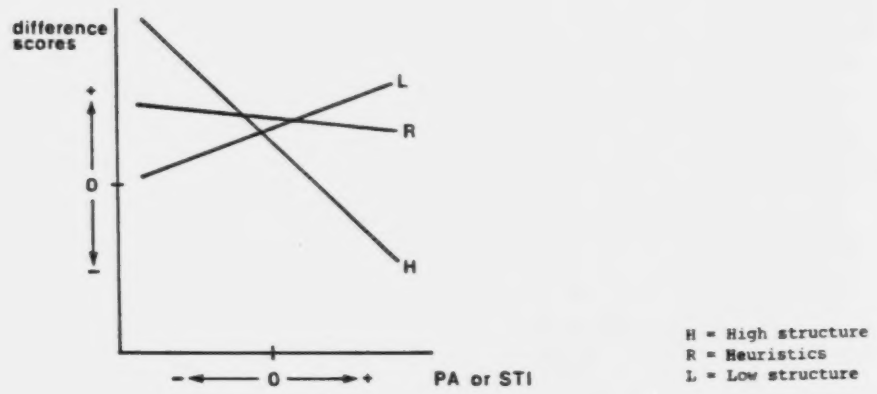

Figure 1. Graphic representation of the significant interactions.

For low PA and low STI students the high structure condition leads to better results (i.e. higher scores on product 2) then the low-structure condition. For high PA and high STI students the opposite is true: they perform best under low-structure conditions. The heuristic condition is as effective for high's as for low's, though for low ability students the high structure condition is slightly more effective.

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Study 2
(This study is also discussed in Schouten, Deijkers & Van Oirschot, 1986)

Research questions

In this study teachers instead of students were subjects of investigation. As in other institutionalized educational systems, technical school teachers play a central role in choosing and controlling instructional events. The technical skills domain, however, has some specific features, which may make the teachers' role even more central. The execution of practice tasks, for instance, demands a lot of organizational work. Besides, to prevent students from harming themselves, teachers have to carefully watch students' manipulating of tools. Moreover, many technical school teachers are themselves conspicuously skillfull, partly because of an earlier career in industry. As a consequence teachers might easily be inclined to heavily structure student behavior and to bring them to imitation of skillful teacher behavior. However, as study 1 has shown, the effectiveness of highly structured instructions may be questioned.

During regular practice lessons teachers' instructions are mainly verbal. In fact little is known about the nature of these instructions. So an exploratory study was devoted to the subject.

Specific research questions for study 2 were:

Do teachers extensively control student behavior or do they stimulate student self-control?

Are teachers aware of the information processing operations students are engaged in when performing complex psychomotor tasks?

To which process components (see model, page 1) do teachers' instructions refer?

Design and method

The verbal behavior of 18 teachers, 10 metal work teachers and 8 electrotechnics teachers, was recorded during regular practice lessons, lasting approximately 1.5 hours each. Afterwards teachers were asked how complex psychomotor tasks should be performed and what aspects of task performance should be considered important. The interviewer avoided mentioning process components as 'goal-image formation', 'analysis' etc., instead teachers were stimulated to talk about task performance in their own words.

The tape recordings of practice lessons and interviews were transformed into written protocols, which were then subjected to content analysis. The interview protocols were categorized by merely counting the number of times a teacher referred to one of the components in the process model. Thereafter the protocols were studied once again to determine whether one or more of the components was emphasized.

To categorize teachers' instructions during lessons the process model served as a starting point, leading to five categories for task-directed instructions. Five more categories were added to classify non-task remarks. To answer the research question about the nature of teachers' instructions, a subdivision of categories was needed. Each instruction concerning task performance was classified as being more 'stimulative' (i.e. enhancing learner-control) or more 'prescriptive' (i.e. enhancing teacher-control). In defining units of analysis a thematic approach was followed (cf. Holsti, 1969).

Figure 2 shows the classification system used to categorize teacher behavior. All protocols were analyzed by one researcher. Re-analysis of two protocols by two other researchers led to high correlations between original and control analysis ($r > .97$).

CATEGORY	DESCRIPTION	SUBDIVISION: STIMULATIVE/PRESCRIPTIVE
	remarks concerning:	
1. Goal-image formation	the creation of mental images of (parts of) the product and its functioning	1.1 the teacher stimulates and helps the student to create his own image 1.2 the teacher describes his own image to the student
2. Analysis	the identification of part problems and transfer of (part) problems into technical terms or models (e.g. electronic schemes or development schemes)	2.1 the teacher stimulates and helps the student to analyze the task himself 2.2 the teacher presents his own task-analysis to the student
3. Planning	the formulation and sequencing of the steps to be taken in a plan of action (also: scribing the piece)	3.1 the teacher stimulates the student to formulate a plan of action 3.2 the teacher prescribes a plan of action
4. Execution	the performance of planned activities	4.1 the teacher stimulates the student to find out for himself how to execute a particular action 4.2 the teacher prescribes or shows how a particular action should be executed
5. Evaluation	the monitoring of ongoing performance and the evaluation of executed actions	5.1 the teacher stimulates the students to regularly evaluate their activities 5.2 the teacher evaluates (part-)products himself
6. Motivation	remarks intented to motivate the student (i.e.: "very well", "I know you can do it")	
7. Discipline	remarks made to maintain classroom discipline	
8. Organization	remarks concerning necessary working conditions, like tools being available	
9. Information	statements about school matters not directly concerning the tasks	
10. Other	statements that cannot be classified in the categories 1 to 9, like simple answers to a question (i.e. "Yes" or "No" or "Good") repetitions or questions like "What do you say?"	

Figure 2: Classification system for teachers' remarks and instructions during practice lessons

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Results

Interviews. When asked about the performance of complex psychomotor tasks teachers often refer to the process components of goal-image formation and analysis (fig.3).

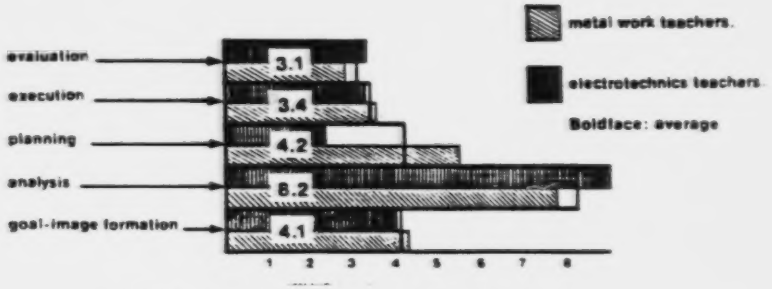

Figure 3. Average number of times a process is mentioned in the interviews.

As can be seen in table 5 many teachers also emphasize the importance of 'knowing what you are going to make and how it functions'. The formation of action plans is (significantly) more often mentioned and also more often judged important by metal work teachers than by electrotechnics teachers. On the other hand none of the metal work teachers emphasizes task analysis, whereas four electrotechnics teachers do so. This kind of trade specific differences also occur during practice lessons. Possible explanations will be discussed later.

Table 5: Number of teachers emphasizing the process components

component	metal work teachers	electrotechnics teachers	total
goal-image formation	8	4	12
analysis	0	4	4
planning	7	3	10
execution	2	3	5
evaluation	1	2	3

Classroom registrations. The results of the analysis of teachers' verbal behavior during practice lessons, according to the system specified in figure 2, are shown in table 6.

Table 6: Means (M), Standarddeviations (SD), Minimum (Min) and Maximum (Max) values for each category of teachers' instructions in percentages of number of remarks (n=18)

	M	SD	Min	Max
goal-image formation	0.9	1.7	0.00	6.83
analysis	24.8	7.5	14.51	37.58
planning	7.3	3.7	2.14	15.24
execution	12.1	5.5	3.40	21.33
evaluation	14.0	4.3	6.54	26.23
motivation	1.5	0.8	0.00	3.24
discipline	2.2	2.7	0.00	11.15
organisation	29.9	7.8	19.21	44.09
information	3.5	1.5	0.86	6.34
other	3.8	1.9	0.82	7.26
	100.0			

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Inspection of table 6 learns that over 40% of teachers' remarks during lessons does not directly concern students' task performance. On the average almost 30% of teachers' instructions concerns classroom organization. The other non-task categories take about 11%. Table 6 also shows that differences between teachers are substantial. Remarkedly few instructions (0.9%) are categorized as referring to goal-image formation. Nine teachers made no remarks about the students' images of tasks whatsoever. This is even more striking, considering the emphasis put on this process component in the interviews.

A schematic representation of teachers' task directed verbal behavior is shown in figure 4.

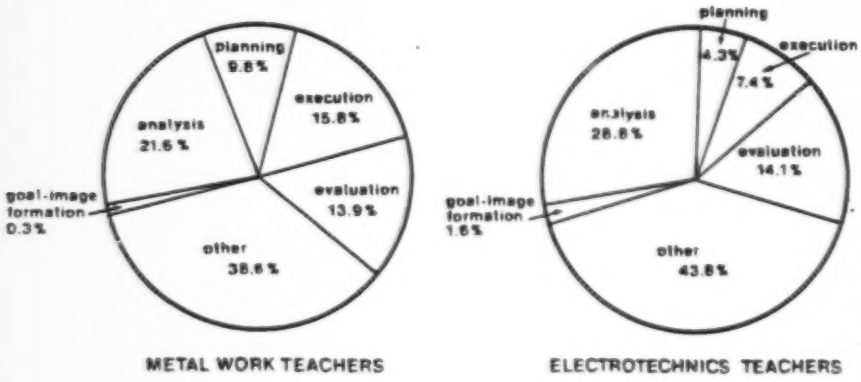

Figure 4: Percentages of teachers' instructions referring to the process components. Metal work teachers and electrotechnics teachers separately

Significant differences between metal work and electrotechnic teachers occur on the categories of 'analysis' (T-value: -2.25), 'planning' (T-value: 4.43) and 'execution' (T-value: 4.85). Electrotechnics teachers more often refer to task analysis, whereas their colleagues of metal work pay more attention to the planning and execution of actions.

On the whole 18.9% of teachers' task directed instructions are regarded as 'stimulative'; as a concequence 81.1% of these instructions is classified as being of a prescriptive nature. So students often are confronted with recipe-like task analyses and plannings, and with ready-to-hand prescriptions and solutions to problems.

Electrotechnics teachers give more stimulative instructions than metal work teachers. As can be seen in table 7 most of these instructions concern task analysis. Metal work teachers, on the contrary, more often give prescriptive instructions, especially concerning planning and execution of actions. Metal work teachers might feel more obliged than electrotechnics teachers to control the planning and execution of actions, in order to prevent loss of expensive materials, as well as to prevent students from harming themselves. As far as task analysis is concerned: some of the metal work teachers simplified this process component by providing for their students a development scheme. In these cases students can be expected to encounter fewer problems and so fewer verbal instructions concerning 'analysis' will be needed.

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Table 7: Significant differences between metalwork and electrotechnics teachers with respect tot percentages of "stimulative" vs "prescriptive" instructions (n=18)

		metalwork teachers	electrotechnics teachers	T
analysis	stimulative	7.4	21.5	-5.09***
	prescriptive	27.7	29.3	-0.52
planning	stimulative	0.1	0.2	-0.42
	prescriptive	15.8	7.4	5.04***
execution	stimulative	0.9	0.4	1.60
	prescriptive	25.1	12.7	4.98***

*** $p \leq 0.001$

Discussion

Rational task analysis (Resnick, 1976) led to the distinction of five process components underlying efficient performance on psychomotor tasks: goal-image formation, analysis, planning, execution and evaluation. Instructional support with regard to these components was found to be differentially effective for students of different ability. Extensive teacher control disrupts high ability students' self-regulation capacities and probably leads only to short-term effects for low ability students.

Study 1 shows that a process-based heuristic approach, stimulating students to perform complex psychomotor tasks in their own way, can be a good help for both high and low ability students. Heuristic instructions permit students not having problems to quickly proceed through the successive processes that lead to the product. However, for students that encounter a problem, suggestions as to the means to deal with it are available. At any stage students themselves control each step of task performance, thereby strenghtening their self-regulation capacities. Low ability students will need more practice than high ability students for these effects to materialize (cf. Schoenfeld, 1979).

Study 2 shows that technical school teachers are inclined to exercise extensive control over student performance. This behavior may rest on: "... the assumption that efficient instruction is necessarily direct instruction in skilled performance strategies ..." (op.cit. Resnick, 1976, p.72). Taking into account the results of study 1, and of earlier studies, such teacher control must be regarded ineffective: high ability students' performance will be suboptimal, whereas for low ability students only short term effects are expected. So a plea is made here to shift control over task performance from the teacher to the learner. Especially in the long run teachers' instructions will be more effective, when they put students in a position where they can invent solutions for problems and develop performance routines themselves (cf. Resnick, 1976).

Special emphasis must be put upon the process component of goal-image formation. In study 1 students were often found to be neglecting the formation of a good goal-image. When asked, many of them answered they did 'understand' the design, although later it appeared they did not have an adequate three-dimensional representation of the product that was to be constructed. As most teachers emphasized: "one cannot make a piece when one does not know what it looks like and what it is for". However, in their classroom behavior teachers referred to details of task analysis and planning, not checking students' images. They might underestimate the difficulty of this step.

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Further research will be needed to show whether in the long run the use of heuristic instructions will lead to the enhancement of student self-control. Further research is also necessary to investigate the nature of 'goal-image formation' and to develop instructional events supporting this important process component.

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